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Chapter V

GEOMETRY OF THE TOOL BIT AND TOOL MATERIALS

GEOMETRY OF THE TOOL BIT AND ITS RELATION TO THE PROCESS OF METAL CUTTING

Geometric Parameters of the Tool Bit.

Surfaces (see Figure 1). Front face is surface (1) along which the chip is removed. The back faces are the bit surfaces facing the work surface: the main back face (2) and auxiliary back face (3). The bevel edge is the narrow strip (4) along the cutting edge of the front face at some angle to the latter. The margin is a narrow strip along the cutting edge of the back face: main back face (5) or auxiliary back face (6).

[Drawings]

Figure 1. Surfaces of tool bit.

Cutting edges. (see Figure 2). The main cutting edge (1), which is performing the basic work of cutting, is formed by the intersection of the front face and main back face. The side-cutting edge (2) is formed by the intersection of the front face and the auxiliary back face. The intermediate cutting edge is where the main- and side-cutting edges are joined, and is either a straight line (3) or a curve (4) with radius r.

[Drawings]

Figure 2.

Basic plane and cutting plane. In considering the cutting tool as a geometrical body, it is sufficient to assume the presence in the cutting process of only one main operating motion; then, the planes, which determine the bit angles, will assume a position with relation to which the tool as a whole is disposed, independent of its setup with relation to the machine. Such planes of reference are the basic plane and the cutting plane.

Tools in the use of which the main working motion is the rotary motion of the workpiece, such as turning cutters in a lathe, are assumed to be set with the contemplated point of the cutting edge at the height of the lathe centers.

The basic plane is the plane normal to the straight line which is tangent to the trajectory described by the motion of a point of the cutting edge on the workpiece. It is either parallel to the axial plane, which passes through the contemplated point of the cutting edge of the tool, in the case of rotary motion of the work, or coincides with the axial plane, in the case of rotating tools. In cutters, the basic plane coincides with the direction of the longitudinal and transverse feeds.

Plane of cutting. This plane is tangent to the cutting surface and passes through the cutting edge (KK in Figures 3-6), normal to the basic plane.

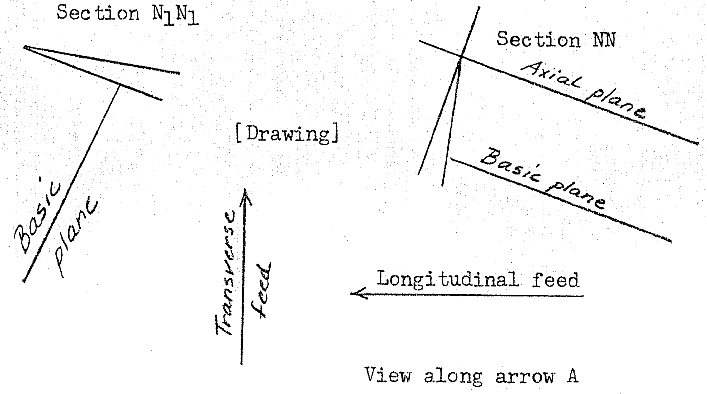
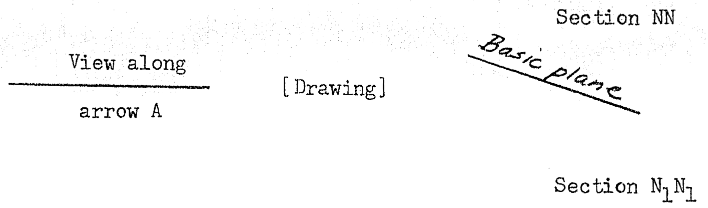

Section N_1N_1
Section NN
Axial plane
[Drawing]
Basic plane
Basic plane
Transverse feed
Longitudinal feed
View along arrow A

Figure 3. Bit angles of threading cutter; KK - plane of cutting.

$\frac{\text{Axial}}{\text{plane}}$ [Drawing] Section NN

$\frac{\text{Basic}}{\text{plane}}$

Figure 4. Bit angles of cut-off cutter; KK - plane of cutting


Section NN
View along arrow A
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Basic plane
Section N_1N_1

Figure 5. Face milling cutter tooth angles; KK - plane of cutting

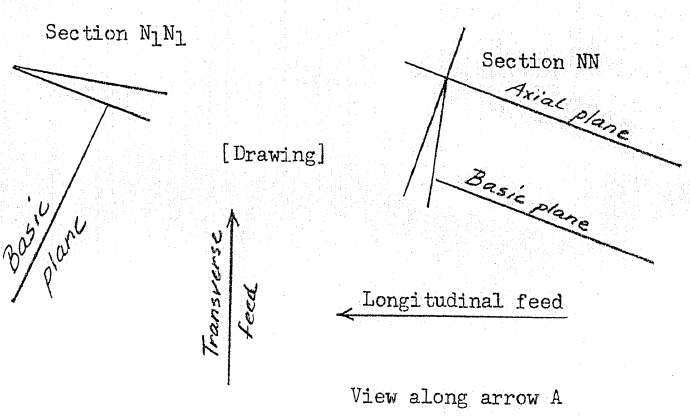
Section N_1N_1
Section NN
Axial plane
[Drawing]
Basic plane
Basic plane
Transverse feed
Longitudinal feed
View along arrow A

Figure 3. Bit angles of threading cutter; KK - plane of cutting.

$\frac{\text{Axial}}{\text{plane}}$ [Drawing] Section NN

$\frac{\text{Basic}}{\text{plane}}$

Figure 4. Bit angles of cut-off cutter; KK - plane of cutting

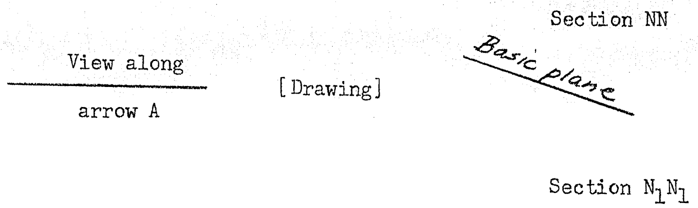
Section NN
View along
arrow A
[Drawing]
Basic plane
Section N_1N_1

Figure 5. Face milling cutter tooth angles; KK - plane of cutting

Basic

plane

[Drawing]

Section NN

View along arrow A

Section N_1N_1

Figure 6. Bit angles of twist drill; KK - plane of cutting.

Main [end-] cutting edge-angles (Figures 3 - 6) are determined in the main intersecting plane (NN), which is normal to the projection of the main cutting edge of tool upon the basic plane.

Front rake angle γ is the angle between the front face and a plane passing through the cutting edge of tool parallel to the basic plane. Back relief angle α is the angle between the main back face of tool and the plane of cutting. Angle of taper β is the angle between the front face and the main back face of tool. Cutting angle δ (conditional) is the angle between the front face of tool and the plane of cutting.

Side-cutting edge-angles (Figures 3 - 6) are determined in a plane, normal to the projection of the side-cutting edge upon the basic plane. For rotating tools, they are determined in a plane normal to the projection of the side-cutting edge upon the axial plane which passes through the contemplated point and is, in that sense, the basic plane.

Side-cutting edge rake angle γ_1 is the angle between the front face of tool and a plane passing through the side cutting edge parallel to the basic plane. Side-cutting edge back relief angle α_1 is the angle between the auxiliary back face of tool and a plane passing through the side-cutting edge normal to the basic plane.

Angles in plan (Figures 3 - 6) are the angles formed by the direction of feed and the projection of the cutting edges upon the basic plane. Main [end] angle in plan φ is formed by the projection of the end-cutting edge and the direction of feed. Side angle in plan φ_1 is formed by the projection of the side-cutting edge and the direction of feed. Intermediate-cutting edge angle φ_0 is formed by the projection of the intermediate cutting edge and the direction of feed. The apex angle in plan ϵ is the angle between the projections of the end-cutting and side-cutting edges upon the basic plane.

Angle of inclination (λ) of main cutting edge (Figure 3 - 6) is the angle formed by the main cutting edge and a straight line lying in the plane of cutting and parallel to the basic plane.

Each one of the above enumerated parameters affects the process of cutting and has the following basic working function: α - to insure the free working motion of the tool bit and reduce back face friction [back relief]; α_1 - to facilitate free motion of the tool bit with relation to machined surface [clearance]; γ - to facilitate the formation and the flow of chip; γ_1 - to facilitate chip formation at the side-cutting edge; φ - to establish the ratio between the thickness of chip and feed, and between the width of the chip and the depth of cut; φ_1 - to determine the degree of finish of the machined surface; λ - to impart the desired direction to the chip flow; φ_0 and r - to establish the locus of transition from the end-cutting edge to the side-cutting edge.

Determination of the Values of Front [Rake] and Back [Relief] Angles.

Front rake angle γ. The optimum value of the front rake angle γ is determined by the conditions of minimum value of deformation, friction, and wear. Favorable conditions for minimum deformation and wear in cutting are created when angle $\gamma = 45$ degrees. The intensity of running wear and temperature increase are reduced with the increase in front rake angle from 30 degrees to 45 degrees. However, when $\gamma = 45$ degrees, the cutting edge of the bit is excessively weakened. The reduction of the front rake angle to 30 degrees leads to an increase in the strength of the cutting edge without any noticeable increase in the intensity of wear and temperature.

The bevel f in the front face of bit increases the strength of the cutting edge.

In the case of hard-alloy-tipped (hard-alloy tips or blades in vitrified bond with basic tool metal) tools, the front rake angle, in the presence of a cutting-edge-strengthening front face bevel, is established as 20 degrees on account of the brittleness of the hard-alloy-in-vitrified-bond blades.

The front face of the cutting bit cames as: (1) a curvilinear surface with bevel (Figure 7); (2) flat surface with bevel (Figure 8); (3) flat surface without bevel.

[Drawing]

Figure 7. Curvilinear front surface with bevel: a - with rectilinear section of lune p; b - without rectilinear section.

[Drawing]

Figure 8. Cutter with flat front surface with bevel.

In relation to the type of cutting tool and the nature of the work to be performed, each of the indicated shapes has its field of application. Table 1 enumerates the recommended forms of the front surface and values for front rake angle γ.

Table 1

Recommended forms of front surface and front rake angle (γ) values

Form of tool bit front face (1)		Type of tool (2)	Workpiece material			Front rake angle γ (in degrees)	
			Steel		Cast iron	Tool material	
			Ultimate tensile strength in kg/mm^2 (3)	H_B (4)	H_B (5)	High-speed tool steel (6)	Hard-alloy-tipped tool steel (7)
With bevel	Flat and curvilinear	Lathe cutters, boring blades	Steel, cast iron, and bronze of all grades			30°	20°
	Curvilinear	Planing and slotting cutters				20°	----
		Lathe cutters, working under impact loads, radial drilling head cutters, deep hole drills					15°

Table 1 (continued)

(1)	(2)	(3)	(4)	(5)	(6)	(7)
Flat, without bevel	Cutters of all types, and milling cutters as follows: cylindrical, face-milling, end-milling, disk-millers (2-side-teeth and 3-side-teeth), corn-blade type, and saws with inserted segments	Up to 60	Up to 180	----	[20°]	[15°]
		Over 60 Up to 80	Over 180 Up to 240	---- Up to 150	15°	
		Over 80 Up to 95	Over 240 Up to 290	Over 150 Up to 200	10°	
	Profile cutters, profile milling cutters	All metals				
	Cutters of all types	Over 95 Up to 120	Over 290 Up to 350	Over 200 Up to 250	----	5°
	Saw-milling, spline-milling, T-shaped, disk-type	All materials			5°	-----

The following values are recommended for the front angle of bevel γ_2 : for high-speed tool steel cutters for lathes it should be zero degrees; for hard-alloy-tipped lathe cutters it should be 10 degrees; for high-speed tool steel planing and slotting cutters it should be 5 degrees.

The basic function of the front angle of the bevel γ_2 is to increase the angle of bevel in the presence of a high value of the front rake angle γ .

The width of the bevel is accepted as

$$f = (0.8 \div 1.0)s \text{ millimeters,}$$

where s is the feed in millimeters per revolution or per double stroke. The lower limit pertains to hard-alloy-tipped tools, the upper limit -- to high-speed steel tools.

The width of the gap l is established in relation to the radius R (see Figure 7) by the formula $l = 2R \sin \alpha$.

The value of the radius R of the gap is to be established in relation to the type of cutter and feed. For lathe threading and boring cutters, $R = (10 - 15)s$ millimeters; for planing and slotting cutters, $R = (30 - 40)s$ millimeters; for recessing and cut-off cutters, $R = (50 - 60)s$ millimeters. The radius of the gap must insure a width of l of no less than 2.5 millimeters. It is recommended that the radius of the gap be not below 3 millimeters.

Back relief angle α. The action of the cutter is not limited to deformation by chip removal, but is extended in the workpiece both ahead of the front face and depthwise beyond the line of shear. The presence of elastic and plastic deformations beyond the line of shear induces operating friction and wear in the back face of the tool bit. The value and the intensity of this wear are basically in relation to the value of the back relief angle.

Back face wear is detrimental to the cutting capacities of the tool to such an extent that its very appearance is the underlying cause of an increase in the cutting effort and pressure on the back face, with an increase in friction and in temperature which, under conditions of accelerated cutting speed, leads to a rapid disintegration of the cutting edge.

A greater back relief angle has a particularly beneficial effect upon the durability of multiblade tools operating under conditions of chip thickness variation, from zero (at the moment of infeed of the cutting edge) to a maximum thickness (at the moment the cutting edge breaks the contact with the workpiece). For a milling cutter, the optimum values of the back relief angles range between 12 and 35 degrees.

In the case of hard-alloy-tipped cutters, it was established that, in rough- and finish-turning of steel, the maximum durability of the tool is obtained when $\alpha = 12 - 14$ degrees.

The optimum value of α in rough-machining with hard alloy-tipped tools is higher than in the case of high-speed steel tools. The higher degree of brittleness present in the hard-alloy-tipped tools leads to the cleaving of layers of the hard-alloy cutting edge in the direction of the action of the radial component of the cutting force, which component grows with wear in the back face of the tool bit. In order to improve the cutting capacities of hard-alloy-tipped tools, it is important to reduce the intensity of wear in the back face of the tool bits, which is attained by increasing the back relief angle.

As a basis for the determination of the value of the back relief angle, the thickness of the chip or feed is taken. Table 2 furnishes the recommended values for the back relief angles.

The values of the angles for cutters are established in relation to the characteristic of the work to be done: whether it is a finishing operation ($s \leq$ 0.2 millimeters per revolution), or a roughing or semi-roughing operation ($s >$ 0.2 millimeters per revolution).

The back relief angle for milling cutters is determined in relation to their type, since a definite thickness of chip is inherent in the design of each type of milling cutter.

Table 2

Recommended values for back relief angle

Number in sequence (1)	Tool		Characteristics or operating conditions (4)	Back relief angle α (5)
	Name (2)	Type (3)		
1	Cutters	Lathe threading, boring, and undercut-high-speed	$s > 0.2$ mm/rev'n	6°
		Planing and slotting -- high-speed	----	
2	Cutters	Lathe threading, undercut, thread-cutting, and profile -- high-speed	$s \leqslant 0.2$ mm/rev'n	12°
		All types of hard-alloy-tipped or bladed	For machining in steel	
	Milling cutters	Cylindrical, face-milling (inserted teeth), disk-type (2-side-toothed and 3-side toothed)	Large-size teeth $z < 1.75 \sqrt{D}$, and with insert blades	
		Profile with back-face-relieved tooth, and corn-blade-shaped for rough-cutting	----	

Table 2 (continued)

(1)	(2)	(3)	(4)	(5)
3	Cutters	All types of hard-alloy-tipped or bladed	For machining in cast iron	15°
		Cut-off	-----	
	Milling cutters	Cylindrical, face-milling (inserted tooth), disk-type (2- and 3-side-toothed)	Small-size teeth $z > 1.75 \sqrt{D}$	
		End-milling and keyway milling	$D > 20$ mm	
		Angle-milling	-----	
		Disk-type saw-tooth milling	$D > 200$ mm	
		Profile-milling (with pointed teeth)	-----	
	Drills	All types	$D \geqslant 20$ mm	
4	Milling cutters	Disk-type straight tooth groove-milling	Small-size teeth	20°
		End-milling and keyway-milling	$D = 10 \div 20$ mm	
		T-groove milling	$D > 25$ mm	

Table 2 (continued)

(1)	(2)	(3)	(4)	(5)
[4]	[Milling cutters]	Disk-type saw-tooth-milling	D = 75 200 mm	[20°]
	Drills	All types	D up to 20 mm	
5	Milling cutters	End-milling and keyway-milling	D up to 10 mm	25°
		T-groove-milling	D up to 25 mm	
6	Milling cutters	Spline-milling	-----	35°

Change in the Values of the Front Rake and Back Relief Angles in the Process of Cutting.

In the process of cutting, and depending on the disposition of the cutting edge points with relation to the axis of the workpiece, the above two angles undergo considerable changes, which are due to: (1) the shifting of the cutting plane due to the complex relative motion of tool and workpiece; (2) the disposition of the cutting edge points in axial planes non-parallel to the basic plane.

In individual cases, the changes in the values of these angles become so considerable that the cutting operation becomes difficult or even impossible.

The values of the bit angles in cutting may be considered as a sum of the following two items:

$$\gamma = \gamma_d - \mu \mp \tau \quad \text{and} \quad \alpha = \alpha_d + \mu \pm \tau ,$$

where γ_d is the original front rake angle; α_d is the original back relief angle; μ is the angle of shift in the trail the cutting plane described in the main intersecting plane as a result of the complex relative motion of the tool and workpiece; τ is the angle of shift in the trail the cutting plane described in the main intersecting plane as a result of the deflection of the cutting edge from the axial plane parallel to the basic plane. The last two terms of the equations for μ and τ reflect the kinematic, and the first items γ_d and α_d -- the physical factors involved in the process of cutting (the technological factors and the quality of the metal being machined).

In most cases, the values of the items μ and τ are so small that they may be disregarded in the determination of the angles γ and α, assuming that $\gamma = \gamma_d$ and $\alpha = \alpha_d$. In some cases, however, the magnitudes of these items attain such high values as to exceed by several times the values of γ_d and α_d, which may lead to the early wearing out,or even to the breaking, of the tool.

Determining the Value of μ.

The trail of the cutting plane changes its disposition as it approaches the back face of the tool bit, and, in so doing, decreases the value of the original back relief angle α_d, simultaneously increasing the value of the original front rake angle γ_d. A visual concept of this may be had from the following comparisons of the work of a planing cutter which has a back relief angle α and a front rake angle γ.

[Drawing] [Drawing]

(a) (b)

Figure 9. Bit angles: a -- during simple motion; b -- during complex motion.

Cross section NN

[Drawing]

Figure 10. Change in bit angles in the process of cutting.

In the first case (see Figure 9, a), a layer of metal is being cut away by the bit as a result of a simple motion represented by vector U. The direction of the trail of the plane of cutting will be parallel to the direction of vector U, and angles α and γ will not change in the process of cutting, retaining their original value, that is $\alpha = \alpha_d$ and $\gamma = \gamma_d$.

In the second case (Figure 9, b), the layer of metal is removed by the cutter as a result of a complex motion (vector W), which is a resultant of two motions: the relative horizontal motion of the bit (vector U in the opposite direction) and the vertical motion of the bit (vector L). The presence of the complex motion changes the direction of the trail of the cutting plane, which direction, in this case, will coincide with the direction of vector W.

Due to the change in direction by the trail of the surface of cutting, the original back relief angle of the bit will be reduced by $\mu = \arctan \frac{L}{U}$, and will become $\alpha_d = \alpha - \mu$, while the front rake angle of the bit will be increased by the same value, and will become $\gamma_d = \gamma + \mu$.

The normal process of cutting requires that the back relief angle be increased, and the front rake angle be reduced, by the value μ.

Determination of μ in lathe turning. In turning, the process of cutting takes place by way of two motions: the rotary motion of the workpiece at a speed of v meters per minute, and the forward motion of the cutter at a feed s millimeters per revolution. Let us assume that we are working with a lathe threading cutter with a cutting edge angle of inclination $\lambda = 0°$, and set on center, it being the case that its bearing surface coincides with the basic plane.

The original angles in the process of cutting in a plane normal to the projection of the cutting edge upon the basic plane (see section NN, Figure 10, a) will be $\alpha_d = \alpha - \mu$ and $\gamma_d = \gamma + \mu$.

The value of angle μ (in the plane NN) is determined by formula

$$\mu = \arctan(\tan \alpha_x \sin \varphi),$$

where α_x is the angle of shift in the trail of the cutting plane in section $X_1 - X_1$ (Figure 10, b). Angle α_x is at the same time the angle of lead of the thread trajectory, described by points of the cutting edge of the bit during the relative motion of the latter in the process of cutting, and is determined by formula

$$\tan \alpha_x = \frac{s}{2\pi\rho}$$

where ρ is the radius of the contemplated point in the cutting edge; s is the feed per one revolution of the workpiece.

The values of α and γ may be expressed by the following formulas:

$$\alpha = \alpha_d + \arctan\left(\frac{s}{2\pi\rho} \sin \varphi\right)$$

$$\gamma = \gamma_d - \arctan\left(\frac{s}{2\pi\rho} \sin \varphi\right).$$

The value of $\arctan\left(\frac{s}{2\pi\rho}\sin\rho\right)$ in conventional lathe operation is not great, and does not exceed 30 - 40 minutes; therefore it can be disregarded, and it may be assumed that $\alpha = \alpha_d$ and $\gamma = \gamma_d$.

In lathe threading when a cutter with a high lead angle value is used, the value of angle μ must be taken into account since it increases sharply with the increase in the pitch of the threads and, when $\frac{s}{d} = 1$, it attains the value of 15 degrees.

Determination of μ in transverse turning. In working with a cut-off cutter, at $\lambda = 0^\circ$ and set on center, the trajectory of cutting is an exact copy of the spiral of Archimedes (see Figure 11).

$$\tan\mu = \frac{s}{2\pi\left(\frac{D}{2} - s\frac{\theta}{360}\right)}$$

where θ is the deflection angle of the workpiece.

Angle μ is rather small, and it will increase in the process of cutting as the cutter approaches the center of the workpiece (when D = 1 millimeter, $\mu = 2^\circ\ 30'$). Therefore, in the case of properly centered cut-off and undercut cutters, the value of μ may be disregarded, and the assumption made that $\alpha = \alpha_d$ and $\gamma = \gamma_d$.

[Drawing]

Figure 11. The trajectory of the motion of a point in the cutting edge of bit in transverse turning.

[Drawing]

Figure 12. Diagram of relieving the back face of a profile milling cutter.

In some cases, the value of μ cannot be disregarded, as, for example, in the case of relieving the back face of milling cutters (Figure 12). The value of angle μ will vary in relation to the disposition of the contemplated point of the cutting edge of the bit as related to the center of rotation O. The maximum value of μ will occur when the cutter will pass through point $\underline{V}_1$ (conditional), and its minimum value -- when the cutter will pass through point A, as per the following equations:

$$\mu_{max} = \mu_{\underline{V}_1} = \arctan \frac{h_k \cdot z}{2\pi[r-(H+h_k)]};$$

$$\mu_{min} = \mu_A = \arctan \frac{h_k \cdot z}{2\pi r},$$

where h_k is the relieving value of the back faces of milling cutter teeth; z is the number of teeth in the milling cutter; H is the height of the milling cutter profile; r is the radius of the milling cutter.

Since the values of α and γ are constants, the values of the original angles $\alpha_{\underline{d}}$ and $\gamma_{\underline{d}}$ for various points of the cutting edge of the cutter will be different, being changed in the process of relieving. For point $\underline{V_1}$ of the cutter, the values of $\alpha_{\underline{d}}$ and $\gamma_{\underline{d}}$ at the end of relieving will be

$$\alpha_{\underline{d}\,\underline{V_1}} = \alpha_{\underline{d}\,min} = \alpha - \mu_{\underline{V_1}}$$

and

$$\gamma_{\underline{d}\,\underline{V_1}} = \gamma_{\underline{d}\,max} = \gamma + \mu_{\underline{V_1}} .$$

For point A of the cutter, at the beginning of relieving, it will be

$$\alpha_{\underline{d}A} = \alpha_{\underline{d}\,max} = \alpha - \mu_A$$

and

$$\gamma_{\underline{d}A} = \gamma_{\underline{d}\,min} = \gamma + \mu_A .$$

Determination of μ when milling with a cylindrical milling cutter. Figure 13 shows two consecutive positions of a cylindrical milling cutter, the second position resulting from the deflection of the milling cutter by angle φ and the displacement of the workpiece by magnitude χ_1 .

[Drawing]

← s mm per tooth

Figure 13. Change in the back relief angle of milling cutter tooth in the process of cutting.

The value of the back relief angle when the point of the tooth is at point A is $\alpha = \alpha_d + \mu$.

Angle α is determined by line AB tangent to the back face of tooth, and line I-I tangent to the circle at point A. Angle α_d is determined by line AB tangent to the back face of tooth, and line II-II tangent to cycloid OC. Angle μ is determined by line I-I tangent to circle at point A, and line II-II tangent to cycloid OC.

The maximum value of μ may be determined by formula

$$\mu_{max} = \arctan \frac{s_o}{\sqrt{\pi^2 D^2 - s_o^2}} .$$

The value s_o (feed per revolution of milling cutter expressed in millimeters) is small as related to πD, and the formula may be simplified as follows:

$$\mu_{max} = \arctan \frac{s_o}{\pi D} .$$

The computation of values for μ, in the case of the values of s_0 and D conventionally used in milling, shows that they are within the range from $0^\circ\ 40'$ to 1°. Hence, in the presence of high-value back relief angles in milling cutters (from 12 to 35 degrees), the value of μ may be disregarded, and the assumption made that $\alpha = \alpha_{\underline{d}}$. By analogy, $\gamma = \gamma_{\underline{d}}$, since an insignificant change in the front rake angle, similarly, cannot substantially affect the work of the milling cutter.

Determination of the Value of τ.

In the process of cutting, the cutting edge of tool, in its working position, does not coincide with the axial plane, which is parallel to the basic plane. In relation to the position of the cutting edge, the value of angle will enter, either with positive or with negative algebraic sign, into the equations which determine the values of α and γ.

[Drawing]

Figure 14. The change in the front rake and back relief angles due to the tool setting with cutting edge above center.

If the tool, in the process of work, makes only one working motion, angles α and γ are determined by the following formulas:

(1) When the cutting edge is set higher than the axial plane, which is parallel to the basic plane (Figure 14):

$$\alpha = \alpha_{\underline{d}} + \tau \quad \text{and} \quad \gamma = \gamma_{\underline{d}} - \tau;$$

(2) When the cutting edge is set lower than the axial plane (Figure 15):

$$\alpha = \alpha_{\underline{d}} - \tau \quad \text{and} \quad \gamma = \gamma_{\underline{d}} + \tau$$

where τ is the angle in a plane normal to the projection of the cutting edge upon the basic plane. This angle is formed by the axial plane OA, passing through the contemplated point of the cutting edge, and plane O_1A, which was accepted as the axial plane in the determination of the angles outside the cutting process.

[Drawing]

Figure 15. The change in the front rake and back relief angles due to the tool setting with cutting edge below center.

Determination of angle τ in the case of a lathe threading cutter.

Section NN

[Drawing]

Section YY

Figure 16. Determination of front rake and back relief angles of cutter when the latter is set with its cutting edge above center line.

Section NN

[Drawing]

Figure 17 The change in the front rake and back relief angles of cutter in the process of cutting, as a result of setting the tool with its cutting edge above center line.

Setting a lathe threading cutter above the center line by magnitude h (see Figure 16) will cause the trail of the cutting plane, in section NN, to deflect from a straight line by the angle τ , which deflection is due to the displacement of point A in the cutting edge with relation to the center line. Then, the values of angles α and γ will be

$$\alpha = \alpha_d + \tau \text{ and } \gamma = \gamma_d - \tau$$

The change in the angle τ occurs in the plane YY normal to the axis of the workpiece and the basic plane.

Figure 16 shows the dispositions of the back relief angle in a plane normal to the projection of the cutting edge (section NN), and in a plane normal to the workpiece axis (section YY).

$$\alpha = \alpha_d + \arctan \frac{h}{\sqrt{R^2 - h^2}} \cos\varphi ;$$

$$\gamma = \gamma_d - \arctan \frac{h}{\sqrt{R^2 - h^2}} \cos\varphi .$$

In the process of cutting, when the cutter is set above the center line, additional changes in the angles α and γ will occur due to the presence of complex motion (see Figure 17).

Angles $\alpha_{\underline{d}}$ and $\gamma_{\underline{d}}$ are determined by formulas

$$\alpha = \alpha_{\underline{d}} + \mu + \tau \quad \text{and} \quad \gamma = \gamma_{\underline{d}} - \mu - \tau .$$

With some degree of approximation it may be assumed:

$$\alpha = \alpha_{\underline{d}} + \arctan\left(\frac{s}{\pi D} \sin\varphi\right) +$$

$$+ \arctan\left(\frac{h}{\sqrt{R^2 - h^2}} \cos\varphi\right);$$

$$\gamma = \gamma_{\underline{d}} - \arctan\left(\frac{s}{\pi D} \sin\varphi\right) -$$

$$- \arctan\left(\frac{h}{\sqrt{R^2 - h^2}} \cos\varphi\right).$$

With relation to the tool operating conditions, the second or third item, or the sum of both, may be equated to zero and eliminated from the equations, due to their insignificant values.

Determination of the value of τ in twist drills.

Section NN

[Drawing]

Figure 18. Changed angles of twist drill bit.

Figure 18 shows the bit of a twist drill, where it can be assumed that $\mu = 0°$; the values of α and γ in the plane NN normal to the projection of the cutting edge upon the basic plane, will be

$$\alpha = \alpha_d - \tau \quad \text{and} \quad \gamma = \gamma_d + \tau ,$$

where

$$\tau = \arctan \frac{b_1}{\sqrt{d^2 - b_1^2}} \cos \varphi .$$

In normal tool sharpening, the value of the original front rake angle γ_d, at the points of the cutting edge near the drill axis, is negative.

Double sharpening of the twist drill and the supplementary sharpening of the transverse edge improve the geometry by changing the values of α_d. For the points close to the drill axis, the angles α_d are slightly reduced. This makes it possible to bring the angles α_d and γ_d up to their optimum values, that is, to increase the durability of the drill and the productivity of the drilling operation.

Thus, the optimum values of the front rake and back relief angles α and γ, which were given in Tables 1 and 2, in relation to operating conditions, metal being machined, type and material of tool, are actually the values of the first items γ_d and α_d in the equations

$$\gamma = \gamma_d - \mu \mp \tau \text{ and } \alpha = \alpha_d + \mu \pm \tau .$$

Usually, with insignificant values of items μ and τ, they may be disregarded and the above indicated Tables used without correcting the given angle values, assuming that $\gamma = \gamma_d$ and $\alpha = \alpha_d$. Only in those cases when, in connection with particular features in the cutting process, μ and τ attain relatively high values, are they to be correspondingly taken into account when using the above cited equations.

Determination of the Values of Angles α_1, φ, φ_1, φ_0, and λ.

Back relief angle of the auxiliary cutting edge α_1.

In determining the optimum value of the back relief angle α_1 of the auxiliary cutting edge it is necessary to proceed from the degree of participation of the latter in the process of cutting and the characteristics of wear sustained by it.

Observations in tool wear show that even in those cases where there is intensive wear in the main back face of bit, no wear is noticeable in the auxiliary back face, and only when operating at very shallow depths of cut are there some indications of wear in that surface.

The absence of wear in the auxiliary back surface is due to the fact that the parameter of the transverse section of the chip, which would be the determining factor in the wear of that surface, is the width b of the chip, which width runs in a transverse direction to the auxiliary cutting edge.

Since the width of the chip usually exceeds the thickness of the chip by many times, it is obvious that the optimum value of the angle α_1 should be relatively constant and should correspond to the optimum value of the back relief angle of the main cutting edge, in the case of a heavy chip.

The above considerations make it possible to establish the constant value of the back angle α_1 of the auxiliary cutting edge: $\alpha_1 = 6$ degrees for all tools. The exception to this rule occurs only in those cases when the auxiliary cutting edge actually plays the part of the main cutting edge, as, for example, when working at an infeed of the threading cutter in multi-tool lathes, or when working with an end-keyway-milling cutter. In these cases, the value of α_1 is taken as 10 degrees.

Main angle as measured in plan φ. The effect of the main angle in plan, in the case of all types of tools, is manifested in its relation to the durability of the latter. With the change in angle φ, the ratio between chip thickness and chip width also changes. By virtue of this, assuming a steady depth of cut and a steady feed, the following are controlled: (1) the length of cutting edge actually performing the cutting,

(2) the thickness of the chip and, as a result of this, (3) the thermal tension at individual sections of the cutting edge. Therefore, a reduction in the main angle, as measured in plan, results in higher tool durability, which fact is a general rule for various tools.

The optimum value of the main angle in plan for any cutting tool will be its least possible value in each specific case. In determining this, it is necessary to take into account its great effect on the cutting force components. This effect, in the case of a lathe cutter, is manifested by an increase in the cutting force, with a decrease of the angle in plan. In the case of drills, reamers, and taps it is manifested by the increase in the moment of torque, with a decrease of the angle in plan.

In the presence of small values of this main angle, there is frequently chatter in the workpiece and vibration in the machine, which result in a lower quality of the machined surface and in an early deterioration of the cutting edge of the tool. These phenomena are particularly strong in the presence of inadequate rigidity of the workpieces.

The selection of the main angle in plan is to be made in relation to the rigidity and configuration of the workpiece, strength of the machine tool and fixture, the value of the machining stock allowance, the tool material, and the form of the front surface of tool.

The effect of the tool material on the durability of the tool is manifested with particular clarity in the determination of the optimum value of the main angle in plan for hard-alloy-in-vitreous-bond (hard-alloy-tipped) cutters. In this case, an increase in cutter durability with a decrease in the main angle in plan is observed down to the value φ = 60 degrees. A further decrease in this angle results in reduced durability. The latter is due to the higher degree of brittleness of the hard-alloy-in-vitreous-bond tool components which will chip under the effect of an accelerated cutting force occurring with a further reduction in the value of the main angle in plan.

In selecting the value of angle φ, it is also necessary to take into account the form of the front face of tool. When the latter surface is curvilinear, and the front rake angle is considerable, the cutting force components are reduced considerably, with the resulting diminution in the sag and vibration of the workpiece. Therefore, in the case of tools with a curvilinear and flat front surface with bevel (in the presence of a large front rake angle), a somewhat smaller main angle in plan is to be selected than in the case of tools with a flat front surface, but without a bevel.

On the basis of the aforesaid, Table 3, which is recommended for the selection of main angles φ in all basic types of tools, was compiled.

TABLE 3

Recommended values for the main angle in plan φ

Group No	Tool			Field of application	Main angle in plan φ
	Name	Type	Material of cutting edge		
(1)	(2)	(3)	(4)	(5)	(6)
1	Cutters with curvilinear front surface with bevel	Threading and boring	High-speed steel	Finish-machining of rigid workpieces	30°
	Milling cutters	Face (bevel-face)-milling		Through-feed milling of rigid workpieces with machining stock allowance up to 3 mm (economical in mass- and large-scale-serial production).	

TABLE 3 (continued)

(1)	(2)	(3)	(4)	(5)	(6)
2	Cutters with front surface bevel	Threading, boring, and undercutting	High-speed steel	Machining workpieces of lowered rigidity	45°
	Cutters with flat front surface without bevel			Machining of rigid workpieces	
	Milling cutters	Face-milling and disk-type milling (two-side-toothed and three-side-toothed)		Through-feed milling of rigid workpieces with machining stock allowance up to 6 mm (economical in mass- and large-scale-serial production)	
3	Cutters	Threading, boring and undercutting	Hard alloy in vitreous bond	Machining of rigid work and of work of lowered rigidity	60°
			High-speed steel	Infeed machining of work of lowered rigidity	

TABLE 3 (continued)

(1)	(2)	(3)	(4)	(5)	(6)
3 (con)	Milling cutters	Face-milling	High-speed steel (con't)	Through-feed milling	60° (con't)
	Drills	Twist		Drilling in steel and in cast iron	
4	Cutter with all forms of front surface	Threading, boring, undercutting and diamond	Hard alloy in vitreous bond	(1) Infeed turning and boring on lathes, multi-spindle machines, and automatics (2) Machining of work of lowered rigidity	75°
		Cut-off	High-speed steel	The cutting off of metal	
5	Cutters	Threading, boring, undercutting and recessing	Hard alloy in vitreous bond and high-speed steel	Machining bar-shaped work and workpieces with given rectangular intersection of surfaces	90°
	Milling cutters	Face-milling, disk-type milling and end-milling	High-speed steel	The milling of given mutually perpendicular work surfaces	

Auxiliary angle in plan φ_1. The basic purpose of the auxiliary angle in plan is to insure the clear motion of the auxiliary cutting edge with relation to the machined surface. The importance of this clearance angle is particularly great in the case of tools that have no back relief angle α_1 of the auxiliary cutting edge, such as disk-type milling cutters for grooving, splining, T-slotting, end-milling without face teeth, and others.

Section N_1N_1 Section N_1N_1

[Drawing]

Figure 19. Face-milling cutter: a -- with angles $\alpha_1 > 0$ and $\varphi_1 = 0$; b -- with angles $\alpha_1 > 0$ and $\varphi_1 > 0$.

[Drawing]

Figure 20. Ratio between the height of roughness of the machined surface (taper section) and the value of the auxiliary angle in plan.

[Drawing]

Figure 21. Face-milling cutter with trimming teeth: 1-- basic tooth; 2 -- trimming tooth.

[Drawing]

Figure 22. Angles φ_1 in uniform groove cutter.

[Drawing]

Figure 23. Angles φ_1 for uniform groove milling cutter.

[Drawing]

Figure 24. Twist drill: D_1 and D_2 -- diameters of drill at the beginning and at the end of the auxiliary cutting edge; M -- the length of the drill bit which is being ground off in resharpening of drill.

In the presence of the angle α_1 and in the absence of the auxiliary angle in plan, the contact of the tool with the machined surface is effected along a straight line, which is the auxiliary cutting edge AB (see Figure 19, a), while in the presence of the angle φ_1 , the auxiliary cutting edge touches the machined surface only at one point A -- the apex of the tooth (see Figure 19, b).

In tools with angle $\alpha_1 > 0$, a decrease in the angle φ_1 results in greater durability. In selecting the value for φ_1 , it is necessary to differentiate between: (1) tools (cutters) in which a variation in the values of φ_1 occurs due to the non-precision setting in the machine -- for these cases the minimum value of angle $\varphi_1 = 5 - 10$ degrees; (2) tools in which the presence of a definite holding base removes the possibility of such non-precision setting (milling cutters, drills) -- in these cases the minimum value of angle φ_1 will be considerably lower.

In the case when the back relief angle of the auxiliary cutting edge α_1 = 0 degrees, the effect of angle φ_1 is manifested by increased durability of the tool, in the presence of an increase in this angle within a certain range.

The effect of angle φ_1 on the degree of finish of the machined surface is manifested by a greater degree of roughness in the machined surface with the increase in the value of angle φ_1, due to an increase in the height of the taper section (see Figure 20), for which reason the value of angle φ_1 in finish-machining is to be lower as compared to rough-machining. In face-milling cutters designed for finishing, trimming teeth are sometimes provided, with small sections of the auxiliary cutting edge disposed at an angle φ_1 = 0 (see Figure 21).

The effect of the auxiliary angle in plan upon the cutting force is manifested as follows. The cutting force component acting in the direction of the tool axis is increased as the angle φ_1 is reduced. Therefore, in order to reduce vibration in the case of non-rigid work, it becomes necessary to increase the value of φ_1 to 30 degrees. In milling, the increase in the cutting force component acting along the tool axis does not cause any considerable vibration. The direction of the cutting force component in this case coincides with the axis of the tool mandrel and the machine spindle, both of which have maximum rigidity in this direction. Therefore, in the case of milling cutters the value of angle φ_1 is selected at its minimum.

Finally, in a series of cases, when the value of angle φ_1 is connected with precision-machining, such as is the case of uniform grooving with recessing cutters (see Figure 22), disk-type milling (see Figure 23), and drilling (see Figure 24), the value of angle φ_1 is determined in relation to the tolerance Δ for the width of the groove V or to the diameter of the hole and length M which is ground off in the resharpening of the bit, as per formula

$$\varphi_1 = \arctan \frac{\Delta}{2M}$$

In these cases the value of angle φ_1 is frequently very small, as a result of which it is expressed, in some tools (drills, reamers), as the difference between dimensions D_1 and D_2 at the beginning and at the end of the auxiliary cutting edge.

Recommended values for angle φ_1 are given in Table 4 below.

TABLE 4

Recommended values for auxiliary angle φ_1 in plan

Group No (1)	Tool		Field of application (4)	Auxiliary angle in plan φ_1 (5)
	Name (2)	Type (3)		
1	Milling cutters	Spline-milling and saw-milling (solid)	-----	2°
		Face-milling, disk-type (2- and 3-side-toothed), end-milling, T-groove milling		
2	Cutters	Recessing, cut-off, tangential, and profile		
3	Milling cutters	Face-milling and end-milling without face teeth		8°
4	Cutters	High-speed steel threading	Lathe turning of rigid work	10°
5		Hard-alloy-tipped threading, undercutting, and boring		15°
6		Threading, undercutting and boring	Infeed machining, also machining work of lowered rigidity	30°
		Outward-bent threading	-----	

TABLE 4 (continued)

(1)	(2)	(3)	(4)	(5)
7	Milling cutters	Recess milling, disk-type for groove-milling and T-groove milling	The machining of uniform grooves	In relation to tolerance for width of groove

Notes: 1 - Rigid work means workpieces in which the ratio $\frac{L}{D} \leqslant 10$.

2 - Work of lowered rigidity means workpieces in which the ratio $\frac{L}{D} > 10$.

Intermediate cutting edge. In almost all cutting tools, the greatest amount of wear is sustained by: (1) the zone of conjugation of the main and auxiliary cutting edges and (2) the near section of the main cutting edge. At these sections occurs the concentrated process of chip formation in the presence of maximum deformation. In addition, the most intensive generation of heat, under conditions unfavorable for its elimination, occurs at these places.

In working with end-milling and face-milling cutters, drills, and some other tools, the maximum cutting speed occurs at the points of conjugation of the main and auxiliary cutting edges, which is also conducive to heat generation.

In order to reduce thermal tension in this zone and to stiffen the apex of the angle formed by the intersection of the cutting edges, it is necessary to reduce the thickness of the chip in this zone by way of creating an intermediate cutting edge with a considerably smaller angle in plan.

[Drawing]

Figure 25. Intermediate cutting edges of cutters: a- curvilinear; b- rectilinear.

[Drawing]

Figure 26. Intermediate cutting edges of milling cutters: a- end-milling cutter; b- face-milling cutter; c- groove-milling cutter.

[Drawing]

Figure 27. Double-sharpened twist drill.

Intermediate cutting edges most widely in use have the form of an arc of a certain radius (see Figure 25, a). Such an arc in the above depicted zone results in a chip of variable thickness, which becomes zero where the transition from the main to the auxiliary cutting edge occurs.

Cutters with rectilinear intermediate cutting edges are shown diagrammatically in Figure 25, b.

In the case of multiple-blade tools, the design of the intermediate cutting edges in the form of an arc causes some difficulties in the attaining of complete uniformity in their form and sizes, and also in the required value of the back relief angle.

In these cases, the most rational form of the cutting edge turned out to be a rectilinear section of definite length (see Figure 26).

In the case of twist drills, the provision for an intermediate cutting edge is known in practical use as the double-sharpening of the drill bit (see Figure 27).

Experimental research has shown that the introduction of intermediate cutting edges with a back angle equal to the back relief angle of the main back face of the tool results in increased durability.

The optimum form of the intermediate cutting edge is its rectilinear form, as the most workable in conformity with the given values of all the geometric parameters involved.

In the case of tools for the machining of work that does not allow any significant values for intermediate cutting edges at the zone of conjugation, minimum value cutting edges, one millimeter long, at an angle of 45 degrees, are to be provided.

The values of the angle in plan for the intermediate cutting edge and the length of the latter in relation to the type of tool and its operating conditions are given in Table 5.

TABLE 5

Recommended values for the angle in plan of the intermediate cutting edge φ_0 and its length f_0

Tool	Angle in plan of intermediate cutting edge φ_0	Length of intermediate cutting edge f_0
Cutters -- threading, boring, undercutting Milling cutters -- face-milling and disk-type (2- and 3-side toothed)	$\frac{\varphi}{2}$	2 mm
Double-sharpened twist drills	35°	0.2d
Cutters -- recessing and cut-off when $\underline{V} \leqq 6$ mm Milling cutters -- face-milling, disk-type groove-milling (2- and 3-side-toothed), and end-milling when $\varphi = 90°$	45°	1 mm
Cutters -- recessing and cut-off when $\underline{V} > 6$ mm	75°	$0.25\underline{V}$

An intermediate cutting edge in the form of an arc of a certain radius is to be used only in those cases when a conjugation along an arc of a corresponding radius is specified for the workpiece.

In lathe cutters the radius of this conjugation is known as the radius at the cutting point. The conjugation is accomplished for high-speed steel cutters, with r = 2 - 3 millimeters, and for hard-alloy-tipped cutters, with r = 0.5 - 1.0 millimeters. Research shows that in the case of finish-turning cutters the increase in the radius at the cutting point is reflected favorably in the cutting capacities of the tool. However, the increase in the radius at the cutting point in the cases of inadequate rigidity of the workpiece results in higher vibration and, consequently, in a deteriorated surface finish. Since machining with hard-alloy-tipped cutters is done at high cutting speeds, which may induce strong vibration, leading, as well as to the deterioration in the finish of the machined surface, to the rapid destruction of the cutting edge of the tool, it is recommended that the radius at the cutting point of the tool be kept to a minimum.

[Drawing]

Figure 28. The conjugation of the cutting edges in cutter with front face bevel.

Tools having a front face bevel, in which case the radius at the cutting point must be within the range of optimum values but at the same time without canceling out the bevel, are to be segregated into a separate group.

As a result of these considerations, the radii at the cutting points of tools with front face bevel are determined in relation to the bevel width and the angles in plan (see Figure 28), and are computed by formula

$$r_{max} \leqslant \frac{f}{2\sin^2\left(\frac{\varphi+\varphi_1}{2}\right)} \text{ millimeters.}$$

Angle of inclination of main cutting edge λ.

[Drawings]

a) b) c)

Figure 29. Angle of inclination of the main cutting edge λ : (a) negative ($-\lambda$); (b) zero ($\lambda = 0$); (c) positive ($+\lambda$).

The value of the angle of inclination of the main cutting edge λ (see Figure 29) is selected by the following data, in relation to the type of cutter, the form of the front surface of the tool, and operating conditions:

Recommended values of the angle of inclination of the main cutting edge of cutters

Type and designation of cutters	Angle of inclination λ of the main cutting edge in degrees
Lathe threading (with front face bevel, undercutting, recessing, and cut-off.	0°
Lathe threading and boring (with flat front surface without bevel) for rough-machining	$+4^\circ$
Lathe threading in intermittent surfaces, planing, for multiple-tool machines and automatics	$+10^\circ$
Finishing cutters	-3°

The Sharpening of the Tool Bit.

The sharpening of cutters may be done either on special sharpening machines or on universal sharpening machines with the aid of special jigs or fixtures.

The fixture for the setting and bracing of the cutter in sharpening on universal sharpening machines is shown in Figure 30.

[Drawing]

Figure 30. Fixture for the setting and bracing of cutters in sharpening on universal sharpening machines.

[Drawing]

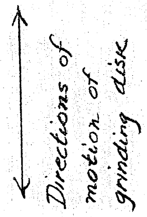

Figure 31. Diagram of formation of curvilinear front surface.

[Drawing]

Figure 32. Elements of the curvilinear front surface.

Frame 1 (Figure 30) moves, together with semi-cylinder 2, cutter holder 3 with cutter, along the table guides of the machine. Semi-cylinder 2 performs an oscillating motion in the frame. The cutter holder 3 allows the cutter to turn in a plane parallel to the upper base plane of the semi-cylinder and the basic plane of the cutter.

In setting, the cutter is braced in the cutter holder and turned to conform with the value of the main angle in plan.

By a turn of the semi-cylinder in a vertical plane, the cutter is set to conform with the value of the front rake angle.

In order to obtain a curvilinear front surface on the cutter, a turn about the vertical axis zz by the magnitude of angle ψ (see Figure 31), relative to the projection of the main cutting edge of the cutter upon its basic plane, is imparted to the grinding wheel. The sharpening is effected by the reciprocal motion of the rotating wheel, parallel to the above mentioned projection of the cutting edge. The outline of the curvilinear front surface obtained by sharpening is a segment of an ellipse in the zone of the minor radii of curvature. For the adjustment of the grinding wheel in the sharpening of the curvilinear profile, formula (10) may be used:

$$\sin\psi = \frac{\sqrt{\dfrac{2RD_k^2\cdot\cos^3\gamma}{D_k - 3R\cdot\cos^3\gamma\cdot\tan^2\gamma}} - d}{D_k - d},$$

where ψ is the angle of turn of the grinding wheel in degrees; R is the radius of the curvilinear profile in millimeters; D_k is the diameter of the grinding wheel in millimeters; γ is the front rake angle of tool bit in degrees; d is the diameter of the grinding wheel profile in millimeters.

In order to determine the depth h of the curvilinear profile (see Figure 32), the following formula is used:

$$h = \frac{D_k}{2}\Bigl(1 - \frac{D_k}{\sqrt{D_k^2 + 4a^2\tan^2\gamma}},$$

where $a = 0.5(D_k - d)\sin\psi + 0.5d.$

In the presence of angle γ_3, the depth of the curvilinear profile in a cutter with a tipped blade will be:

$$h_0 = \frac{D_K}{2} - \frac{D_K^2 + 4a^2 \tan\gamma \cdot \tan\gamma_3}{2\sqrt{D_K^2 + 4a^2 \cdot \tan^2\gamma}} \cdot$$

The sharpening of milling cutters and other multiple-blade tools is done along the front and back surfaces. The cylindrical margin on the back surfaces of the milling cutter teeth is not to exceed 0.03 - 0.05 millimeters.

The sharpening of the front surface of tools with sharp-pointed teeth. The front surface of tools with straight teeth is sharpened with the flat surface of a plate-shaped grinding wheel.

[Drawing]

Figure 33. The sharpening of the front surface of tool with helical teeth.

The front surface of tools with helical teeth is to be sharpened with the tapered surface of the grinding wheel (see Figure 33), since sharpening it with the flat surface of the wheel would result in the improper form of the front surface of the tool and in the reduction of its front rake angle.

In order to obtain the proper front rake angle of tool γ, it is necessary to turn the cutting point of the tooth being sharpened in such a way that its front surface is at distance h from the tool axis (see Figure 34).

(a) (b)

Figure 34. Diagram for the setting of milling cutter tooth in the sharpening of its front surface.

The magnitude of shift (h) of the tool axis in a direction normal to the grinding plane, in the case of tools with straight teeth, coincides with the transverse displacement of the machine table, and is determined from the triangle OAK (see Figure 34, a):

$$h = \frac{D}{2} \sin \gamma,$$

where D is the tool diameter; γ is its front rake angle.

The magnitude of displacement h of the tool axis in a direction perpendicular to the cutting edge, in the case of tools with helical teeth (see Figure 34, b) is determined from the condition of the presence of an ellipse in a section normal to the cutting edge, and the angle δ of the grinding wheel:

$$h = \frac{D}{2} \frac{\sin \gamma}{\sqrt{\cos^2(\gamma+\delta) + \sin^2(\gamma+\delta)\cos^2\omega}}$$

where ω is the angle of inclination of the helical teeth (the flutes).

In order to obtain the necessary shift of the tool in the sharpening machine, it is practically necessary to shift the machine table with the tool or the grinding head (depending on the design of the sharpening machine) by a value:

$$x = \frac{D}{2} \frac{\sin(\gamma+\delta)}{\sqrt{\cos^2(\gamma+\delta)+\sin^2(\gamma+\delta)\cos^2\omega}}$$

In order to avoid computations and to facilitate set-ups, it is recommended that a device, shown in Figure 35, be used.

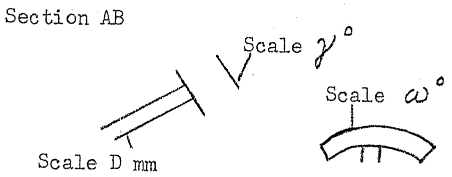

Figure 35. Device for the setting of milling cutters and other multiple-blade tools in the sharpening of the front surface.

The device is braced with the aid of fulcrum supports (1) on the mandrel or in the center of the chuck of the sharpening machine, after a proper setting, by its scales, to conform with the requisite front rake angle γ, has been effected. Then the tool diameter D and the helical tooth angle ω, with the aid of the carriage plane I - I, are mutually superposed with the generatrix of the grinding wheel cone, by which operation the requisite value of displacement h is automatically secured.

In sharpening tools with straight teeth, the setting can be effected with the aid of a device shown diagrammatically in Figure 36.

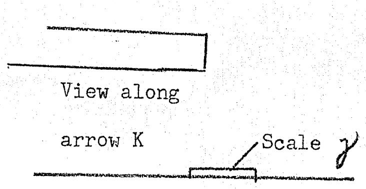

Figure 36. Device for setting of milling cutters and other multiple-blade tools with straight teeth in sharpening the front surface.

Having determined the value of H by the scale on the reverse side of ruler (4), one adjusts the support (3) by the same value. By the placing of the device, with the aid of a fulcrum support (1) on the cylindrical part of the tool or center of the tool-holding chuck, and by mutually superposing the plane I-I and slide (2) with the plane of the grinding wheel (or with the generatrix of the grinding wheel cone), the requisite value of the "sharpening" displacement h is secured.

Sharpening of the front surface of tools with back-face-relieved teeth. The sharpening of milling cutters and other tools with back-face-relieved teeth is done only along the front surfaces. As a base for bracing the tools, the back edges of the teeth which are to be sharpened are used. These back edges of the teeth, in the manufacturing of the tools, are index head-ground in order to secure their uniform circular spacing.

The feed per depth of the layer being removed by each pass, along all the teeth, is to proceed by turning the tool about its axis to a corresponding value, which is accomplished by advancing the adjustable stop (Figure 37).

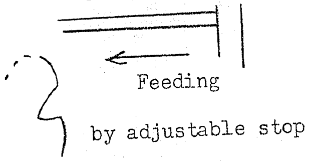

Figure 37. Diagram for the sharpening of front surface in back-face-relieved tools.

[Drawing]

Figure 38. The setting of a cup-shaped grinding wheel with relation to the tool being sharpened.

[Drawing]

(a)

[Drawing]

(b)

Figure 39. Diagram and device for the setting of a multiple-blade tool in the sharpening of the back surface.

[Drawing]

Figure 40. Diagram for the sharpening of the back surface of a multiple-blade tool with a disk-type grinding wheel.

Sharpening the back surface. The sharpening of the back surface of a tool with sharp-pointed teeth is to be done with the aid of a cup-shaped grinding wheel. In order to reduce the surface of contact and heating in the tool when sharpening with a cup-shaped grinding wheel, it is necessary to turn the axis of the latter in a horizontal plane relative to the axis of the tool being sharpened, by 1 - 2 degrees (see Figure 38).

The obtaining of the requisite back relief angle in sharpening with a cup-shaped grinding wheel is accomplished by turning the tool about its axis in such a way that the cutting point A of the tooth being sharpened sustains a displacement equal to the value H (see Figure 39, a):

$$H = \frac{D}{2} \sin \alpha ,$$

where D is the tool diameter; α is the back relief angle.

The proper position of the cutting point of the tooth is fixed by a stopping device which is to be set as close as possible to the cutting edge of the tooth being sharpened. In sharpening tools with straight teeth, a wide stopping device is to be used. In the case of helical teeth/ a wide stopping device with beveled-off angles,and/ in the case of face-milling teeth, a narrow stopping device, is to be used.

The setting of the stopping device for height can easily be accomplished with the aid of a regulator shown diagrammatically in Figure 39, b. With the aid of the scales present in the device, the following is done: (a) the ruler (1) is set to a value equal to half the diameter of tool $\frac{D}{2}$; (b) the inner semi-disk (2), together with the ruler, is turned by the value of the back relief angle α; (c) the outside semi-disk (3), together with the inside semi-disk and ruler, along the notch of the supporting frame (4) are set to the height of the centers of the sharpening machine.

The stopping device is fed to point A in the cut-out of ruler (1), by virtue of which the cutting point of the tooth being sharpened is displaced by the value H.

When sharpening tools with a small number of teeth, a disk-type grinding wheel may be used (see Figure 40). In this case the cutting point of the tooth being sharpened must lie in one horizontal plane with the tool axis, and the grinding disk axis is to be above this plane by the value

$$H = \frac{D}{2} \sin \alpha .$$

The sharpening of twist drills along the back surface, for the obtaining of the requisite values of their geometric elements, is to be done on special drill-sharpening machines.

In this case the forming of the back relief angle α is based on the fact that the back surfaces of the drill are parts of helical surfaces of imaginary sharpener cones (Figure 41), and its cutting edges coincide with the generatrices of these cones. The axes of the imaginary cones are mutually perpendicular and form with the drill axis the angle θ = 45 degrees, and in horizontal projection they are displaced with relation to the drill axis by the magnitude pD = 0.07D (where D is the drill diameter). By virtue of the aforesaid, positive values are attained for the back relief angle.

The face plane of the cup-shaped grinding wheel which, in the process of sharpening, performs a rotary and a reciprocating motion, coincides with the generatrix of the imaginary cone, the axis of which is the pivot axis of the drill-holding chuck. The drill braced in the chuck at angle θ° to the chuck axis, in the process of sharpening, performs an oscillating motion around the chuck axis.

The drill is to be properly clamped in the chuck lips gripping it along the margin surfaces (see Figure 42), at a distance yD (see Figure 41) determined from triangles ABC and BCE:

$$yD = \frac{BC \sin\psi}{\sin(180-\varphi)} = \frac{xD \sin\psi}{\sin\Theta \sin\varphi}.$$

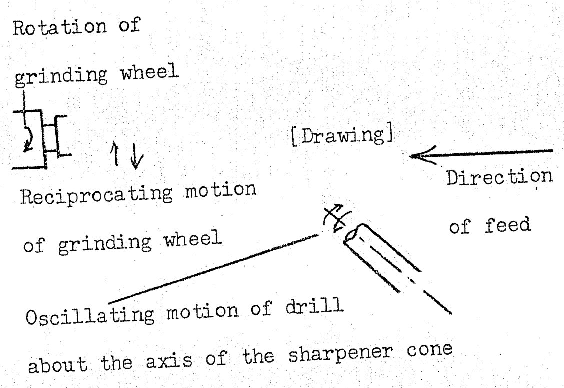
Rotation of
grinding wheel
[Drawing]
Direction
of feed
Reciprocating motion
of grinding wheel
Oscillating motion of drill
about the axis of the sharpener cone

Figure 41. Principal diagram for sharpening of twist drills.

[Drawing]

Figure 42. Diagram for bracing of twist drill in sharpening.

[Drawing]

Figure 43. Device for sharpening small twist drills.

To determine the location of the drill gripping clamps, data furnished in Table 6 below can be used. The Table indicates distances z from the peripheral points of drill cutting edges to the clamp lips (see Figure 41).

TABLE 6

Diameter of drill in mm	Conventional drills	Drills for soft steel	Drills for aluminum and copper	Drills for brass
10	6	6	3.5	7
15	7	7	4	8
20	8	7.5	5	9
25	9	8.5	5.5	10
30	10	9	6	11
35	11	9.5	6.5	---
40	11.5	10	7	---
45	12	10.5	7.5	---
50	12.5	11	8	---
55	13	11.5	8.5	---
60	14	12	---	---
65	14.5	12.5	---	---
70	15	13	---	---
75	16	14	---	---

In order to obtain the requisite value of the angle at the cutting point of the drill (2φ), it is necessary to change the magnitude of the angle at the apex of the sharpener cone 2ψ by a turn of the supporting carriage on which the axis of oscillation of the drill holding chuck is situated, since: $2\varphi = 2\psi + 2\Theta$ (see Figure 41).

To sharpen the back surfaces of small drills (less than

4 millimeters), a device, presented diagrammatically in Figure 43, can be used. Into sleeve (1) of swivel bracket (2), which is rotating in frame (3) and is oscillating at an angle ψ = 13 degrees to the face plane of the grinding wheel, are inserted removable bushings (4) (of a size in relation to the diameter of the drill). The drill axis (5), and also the axes of the bushing (4) and of the sleeve (1), lie at an angle Θ = 45 degrees to the axis of oscillation of the swivel bracket (2).

The underlying principle of sharpening drills in this device is similar to the sharpening principle in the machine.

When angle ψ = 13 degrees and Θ = 45 degrees, only the conventional sharpening of the drill can be accomplished in the device, since

$$2\varphi = 2\psi + 2\Theta = 26 + 90 = 116^\circ.$$

The sharpening of the ferrule and margin of the drill is done by hand with the aid of a rounded-edge grinding wheel mounted on a universal or plain drill sharpening machine.

CHECKING THE GEOMETRY OF THE CUTTING TOOL

Checking the back relief angle. The checking of the back relief angle of a cutter with a limit gage (see Figure 44) and measuring it with a protractor (see Figure 45) is done in a plane N-N normal to the projection of the cutting edge upon the basic plane. The measuring of the back relief angle with a universal protractor for cutters (see Figure 46) is convenient, since the protractor can be superposed upon the cutter without removing the latter from the sharpening machine.

The checking of the back relief angle in drills with the aid of a limit gage is shown in Figure 47. The checking of the back relief angle of a multiple-blade tool by using a limit gage is shown in Figure 48, and by using a protractor, in Figure 49.

[Drawing]

Figure 44. Checking the back relief angle of cutter with limit gage.

[Drawing]

Figure 45. Measuring the back relief angle of cutter with the aid of a protractor.

Section NN

[Drawing]

Figure 46. Measuring the back relief angle of cutter with the aid of a universal protractor.

[Drawing]

Figure 47. Checking the back relief angle of a drill with a limit gage.

[Drawing]

Figure 48. Checking the back relief angle of milling cutter with limit gage.

[Drawing]

Figure 49. Measuring the back relief angle of milling cutter with the aid of a protractor for multiple-bladed tools.

The checking of the front rake angle and of the form of the front surface of cutters and milling cutters is a procedure similar to the checking of the back relief angle. A limit-type gage is used for checking the angle of sharpening after the back relief angle has been checked. In measuring the front rake angle, the measuring arm of the protractor must touch the front surface of cutter and must also lie in a plane normal to the projection of the main cutting edge upon the basic plane. The curvilinear form of the front surface is checked with the aid of a limit gage (Figure 50), in which case the measuring of the front rake angle is effected with the aid of a universal protractor (Figure 51).

The principle of measuring the back relief and front rake angles of multiple-blade tools with the aid of limit gages and universal protractors reduces itself to the determination of angles α_x and γ_x (Figure 52), the value of which, with given values for the back relief and front rake angles, is in relation to the number of teeth z, and is determined by the formulas:

$$\alpha_x = \alpha - \frac{\epsilon}{2} = \alpha - \frac{180}{z}$$

and

$$\gamma_x = 90 - \frac{180}{z} - \gamma_T\,,$$

where $\gamma_T = \arctan\left(\frac{\tan\gamma}{\cos\omega}\right)$; γ is the front angle of tool in the normal (main intersecting) plane; ω is the angle of inclination of the helical tooth.

[Drawing]

Figure 50. Checking of the front rake angle and of the front surface form of cutter with the aid of a limit gage.

[Drawing]

Figure 51. Measuring the front rake angle and checking the curvilinear form of front surface of cutter.

[Drawing]

Figure 52. Checking diagram for limit gage and protractor angles in the case of multiple-blade tools.

Checking the main cutting angle in plan is done with the aid of a limit gage and universal protractor (Figures 53 and 54).

[Drawing]

Figure 53. Checking main cutting angle in plan with the aid

of a limit gage.

[Drawing]

Figure 54. Measuring the main cutting angle in plan with the aid of a universal protractor for cutters.

Checking the auxiliary angle in plan is done with a limit gage or a universal protractor in a manner similar to the checking of the main cutting angle.

In the case of drills and reamers, the auxiliary angle in plan, due to its small value, is determined by taking the micrometer readings of the diameters at the beginning and at the end of the auxiliary cutting edge (inverted cone).

In the case of milling cutters, the measuring of the auxiliary angle in plan is done with the aid of a protractor, after which the measurement is checked with the aid of a ruler for a gap of light (see Figure 55).

[Drawing]

Figure 55. Checking the auxiliary angle in plan of a milling cutter with ruler for a gap of light.

Checking the angle of inclination of the main cutting edge of cutters is done with the aid of a protractor in a plane normal to the bearing plane and passing through the cutting edge.

Tolerances for the geometric parameters of cutters and milling cutters are cited in Table 7.

TABLE 7

No in sequence	Geometric parameters	Value of angle	Tolerance
1	Back relief angles α and α_1	Up to 20° Above 20°	+ 2° + 3°
2	Front rake angle γ	Up to 20° Above 20°	+ 2° + 3°
3	Main cutting angle in plan φ	---	+ 3°
4	Auxiliary cutting angle in plan φ_1	Up to 0°30' From 0°30' to 1° From 1 to 10° Above 10°	+ 0°15' + 0°30' + 1° + 2°
5	Angle of inclination of main cutting edge λ	---	+ 1°

Checking for symmetrical disposition of the cutting components of milling cutters and other multiple-blade tools (checking for free play) is done with the aid of an indicator. The departure values between adjacent teeth are determined as the arithmetical mean of three indicator reading.

HIGH-SPEED CUTTING OF METALS

The basic practical solution of the problem of high-speed metal cutting proposed in the USSR as far back as 1936 consists in the utilization of the heat which is generated in cutting as a result of the plastic deformation of the metal layer being removed. [17]

Footnote: The method of increasing productivity when machining workpieces preliminarily heated by bringing in the heat from outside sources found no industrial application, since it called for specially equipped operating premises. Particularly, when attempting to utilize, for localized pre-heating, high-frequency currents, a powerful high-frequency installation is necessary, and the machining of work with variable cross sections is made difficult.

In the presence of low cutting speeds, the liberated heat pervades (by convection) the material being machined. Additionally, with low cutting speeds, the temperature in the metal layer being removed does not exceed 300 - 400 degrees Centigrade, that is, it is considerably below the maximum economical cutting temperature value, which is 500 - 600 degrees Centigrade.[12]

In the presence of high cutting speeds, the amount of energy being conveyed from the outside per unit of time is increased, while the time for the elimination of the heat is reduced. Hence, with high cutting speeds, the increased amount of heat is concentrated in the zone of the metal layer being separated, resulting in a considerable temperature increase in this zone, up to 600 - 800 degrees Centigrade.

It must, however, be taken into account that in cutting, simultaneously with the rise in the temperature of the machined metal, the temperature of the tool bit is also increased. Therefore, the limiting factor, as far as the rise in temperature is concerned, is the thermal durability of the tool bit, that is, the retention by the tool bit of its cutting capacity under conditions of high temperature. This condition, under the above indicated temperatures, is satisfied by tungsten-titanium-cobalt alloys in vitreous bond with tool steel.

High-speed metal cutting found its widest application in lathe work and milling, and it is known as "high-speed turning" and"high-speed milling".

The solution of the problems in high-speed metal cutting is inherently related to the establishment of a corresponding geometry of the tool bit and of cutting practices, the value of which, proceeding from the specifics of high-speed cutting, must be established to conform with considerations substantially different from those that were prevalent in the selection of the above indicated parameters for the conventional methods of metal cutting.

For example, in determining the front rake angle in high-speed cutting, it is necessary to proceed from the tendency to a temperature rise on the part of the metal chip in process of separation, by way of an increase in its deformation. The latter is attained by decreasing the front rake angle until it assumes negative values. Simultaneously, there is an increase in the strength of the tool bit, which is of great importance, considering the brittleness of hard alloys.

As a result of extensive research, the following optimum geometric parameters of the tool bit for high-speed turning and high-speed milling are recommended.

1 - The front rake angle and the form of the front surface of the tool bit. In machining with hard-alloy-tipped cutters, when high cutting speeds are employed, the optimum value of the front rake angle is to insure: (1) a higher degree of deformation in the metal layer being separated in order to raise the temperature in said layer; (2) a greater strength of the tool bit; (3) a reduction in the external friction of the chip against the front surface of the tool bit.

A negative value of the front rake angle satisfies the first two conditions. At the same time, a negative front rake angle does not insure a reduction in the external friction of the chip against the front surface of the tool bit. All of the above stipulations are satisfied by a double front surface (flat surface with bevel).

The value of the front rake angle γ, in the presence of a flat front surface of tool bit, is to be within the range of minus 10 to minus 15 degrees.

In the presence of a double front surface these values are to be retained for the angle of bevel γ_2. In such a case, the bevel is to be of considerable width, in order to create in the machined metal an adequate bearing surface that will insure the proper formation of chip on it. In this case, the front rake angle γ is to have a positive value, in order to reduce external friction in the flow of the chip along the front surface of the bit.

2 - Back relief angle. In relation to the specifics of hard-alloy-tipped tool bit wear, the value of the back relief angle is to remain within the range of 14 - 16 degrees.

3 - Main and auxiliary cutting angles in plan. The cutting force greatly affects the durability of hard-alloy-tipped tool bits. For this reason, the value of the main cutting angle φ is to be 60 degrees, since then the cutting force will be at its minimum value.

With the increase of the auxiliary angle in plan, the radial component of the cutting force is reduced. Hence, an increase in the value of φ_1 has a favorable effect on the durability of hard-alloy-tipped tool bits. The recommended values of this angle are not to be below 10 degrees.

Intermediate cutting edge. In high-speed metal cutting, the intermediate cutting edge is to be rectilinear with an angle in plan φ_0 = 20 degrees.

The optimum values of the geometric parameters of the tool bit, as used in high-speed metal cutting, are cited in Table 8 below.

TABLE 8

Geometric parameters of tool bit in high-speed metal cutting

Form of the front surface of bit	Metal being machined		Geometric parameters										
			Main cutting edge						Auxiliary cutting edge			Intermediate cutting edge	
			γ	f	γ_z	α	λ	φ	α_1	φ_1 Cutters	φ_1 Milling cutters	f_0	φ_0
Flat with bevel	Steel	$\sigma_b < 65$ kg/mm^2	+20°	5s mm	-10°	15°	+5°	60°	8°	30°	10°	2 mm	20°
		$\sigma_b > 65$ kg/mm^2			-15°								30°
	Cast iron			1s mm	0								
Flat without bevel	Steel	$\sigma_b < 65$ kg/mm^2	-10°	---	---								20°
		$\sigma_b > 65$ kg/mm^2	-15°										30°
	Cast iron		+5°										

CUTTING TOOL MATERIALS

The selection of material for the cutting tool must be in relation to the type, designation, form and volume of the tool, to operating conditions, heat treatment, and the degree of finish.

Detailed data on cutting tool materials are furnished in Chapter VIII, volume 3 (tool steels) and Chapter III, volume 4 (hard alloys) of the encyclopedic manual *Mashinostroyeniye* (Machine Building).

In determining the grades of steel for the fabrication of various tools, the use of Table 9 is recommended.

TABLE 9

Grades of steel for various tools

Name of tool (1)	Grades of steel		
	Carbon (2)	Alloy (3)	High-speed (4)
Thread-cutting chasers, disk-type and prismatic, with non-ground profile	U12A	9KhS	----
Countersinks, inserted blade and tapered	U12A, U10A	9KhS	R, EI-347
Counterbores	U12A, U10A	9KhS	----
Blades for inserted blade countersinks	----	----	R, EI-347

TABLE 9 (continued)

(1)	(2)	(3)	(4)
Tooth-cutting tools (slotters, chasers, cutters, cutting heads, shavers)	----	----	RF1, R, EI-347
Shanks for cutters, cutting heads, countersinks, reamers, etc.	----	40Kh, ShKh15	----
Hand taps (with non-ground profile)	U12A, U10A	9KhS	----
Nut-threading taps, machine, screw-die, master taps, with non-ground profile	U12A, U10A	9KhS	----
Files (furnace-hardened). .	U12A, U10A	Kh	----
Files (high-frequency-current-hardened)	U8A	----	----
Circular chaser (also square-, hexagonal-, locksmith-) die heads for slanting die stock, pipe screw-dies	----	9KhS	----
Screw-dies, knurled	----	Kh12M, 5KhNM	----
Screw-dies for thread-cutting heads, with non-ground profile	----	9KhS	----

TABLE 9 (continued)

(1)	(2)	(3)	(4)
Screw-dies for thread-cutting heads, with ground profile	----	----	R, EI-347
Broaches -- keyway, spline, circular, square, for external broaching, forming, calibrating and the like	----	KhVG, 9KhS, KhG	RF1, R, EI-347
Tool blocks for welded tools (gear cutters, chasers, slotters, shavers and the like)	----	40Kh, ShKh15	----
Reamers -- hand, machine, tapered, inserted blade	U12A	9KhS	----
Boiler reamers	U12A	9KhS	EI-347
Blades for inserted blade reamers	----	9KhS	EI-347
Cutters -- threading, cut-off, undercutting and the like	----	----	RF1, R, EI-347
Profile cutters, disk-type and prismatic	----	----	RF1, R, EI-347
Drills (0.25 - 1.0 millimeter diameter)	U12A, U10A	----	----

TABLE 9 (continued)

(1)	(2)	(3)	(4)
Twist drills and centering drills of all sizes	U12A, U10A	9KhS	RF1, R, EI-347
Milling cutters -- cylindrical type, face-milling, disk-type (3-side-toothed), groove-milling, keyway-milling, recess-milling, taper-milling for dies, and the like	----	9KhS	RF1, R, EI-347
Milling cutters with back-relieved teeth of various profiles (non-ground profiles) . .	U12A	9KhS	----
Milling cutters -- angular (all profiles), end-milling, cylindrical	----	9KhS	----
Thread-milling chasers and disks, with ground profile . . .	----	----	R, RF1, EI-347
Thread-milling chasers and disks, with non-ground profile .	----	9KhS	----
Disk-type gear-cutting hobs up to Module 1	U12A	9KhS	----
Disk-type gear-cutting hobs (module above 1)	----	9KhS	----

TABLE 9 (continued)

(1)	(2)	(3)	(4)
Finger-type gear-cutting hobs	----	----	*RF1*, *R*, *EI-347*
Worm-gear hobs, worm gear for non-evolute profiles and spline shafts, worm gear tapered -- with ground profile	----	----	*RF1*, *R*, *EI-347*
Worm-gear hobs, worm gear for non-evolute profiles and spline shafts, worm gear tapered -- with non-ground profile	----	*9KhS*	----
Blades for inserted-tooth milling cutters	----	----	*RF1*, *R*, *EI-347*
Welded tool shanks	Steel *40*, *45*	----	----

Note: In all cases cited, steel of grade *EI-262* may be used instead of steel of grade *EI-347*.

Considerable deformations occurring during the heat treatment of carbon steel disqualify it for use in an entire series of tools: large cylindrical milling cutters, thin recess-milling cutters, complex-profile milling cutters, worm-gear hobs, thread-cutting tools, and the like.

Alloy steel 9KhS, oil-hardened, which is subject to minimum distortion in heat treatment and is amenable to through-tempering and step-hardening, finds a much wider field of application. Its deficiency is a less satisfactory machinability, as compared to carbon steel, particularly in thread-cutting operations.

Ground profile tools, such as taps, dies for die-cutting heads, and the like, are fabricated only from high-speed steel or its substitutes, since tools fabricated from steels of other specifications are tempered in grinding. Table 9 cites only the basic substitutes of high-speed steel.

Metalloceramic hard alloys are used for cutting tools in the form of standard blades for cutters and for inserted-blade tools (milling cutters, drills, countersinks, reamers). The blade material is selected in relation to the type of work material. For machining cast iron, blades fabricated from VK8 and VK6 tungsten carbide alloys are used. For machining steel, blades fabricated from T15K6, T5K6, and T5K10 carbide-titanium-tungsten alloys are used.

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